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COMPOSITE LOAD SPECTRA FOR SELECT SPACE PROPULSION STRUCTURAL COMPONENTS*

J. F. Newell
Rocketdyne Division, Rockwell International
Canoga Park, California

The objective of this program is to develop generic load models to simulate the composite load spectra (CLS) that are induced in space propulsion system components representative of the space shuttle main engines (SSME). These models are being developed through describing individual component loads with an appropriate mix of deterministic and state-of-the-art probabilistic models that are related to key generic variables. Combinations of the individual loads are used to synthesize the composite loads spectra.

A second approach for developing the composite loads spectra load model simulation, the option portion of the contract, will develop coupled models which combine the individual load models. Statistically varying coefficients of the physical models will be used to obtain the composite load spectra.

The need for this type of technology advancement is apparent from the demand for higher performance, lighter weight, components that yield higher operating pressures, temperatures, vibration and flow loads, Figure 1. The difficulty in installation, cost, and potential for new failure mechanisms limit the required instrumentation to adequately define or verify loads. Proper quantification of loads are required to minimize adding conservatism on conservatism and to specify results so they can be accurately used for structural analysis and risk assessment.

Rocketdyne is teamed with Battelle to develop this methodology. Rocketdyne is using their background and expertise for the advancement in the loads definition and analysis methods along with the extensive SSME test database for comparitive information. Battelle is utilizing their expertise to develop an advanced probabilistic code to represent the individual loads and load spectra. Rocketdyne is packaging this total work in an easy to use expert system type code. The following discussion covers an overview and Rocketdyne's effort. Battelle's contribution is presented in a separate report.

The CLS development is a 3-year base program with a 2-year option program. The first 2 years of the base program have been completed. The effort has three major tasks: probabilistic model theory and development, code development and code validation and verification, Figure 2. Four classes of rocket engine components are being used as examples for the load development--turbine blades, transfer ducts, LOX posts and engine system ducts, Figure 3 and 4. The available SSME instrumentation for use in developing SSME related statistical data and load verification are also shown in Figure 3.

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The probabilistic modeling requires simulation of the individual loads summarized in Figure 5. Several shape simulations are required to characterize these loads. The start and cutoff transients include a nominal, random over nominal and spike load shape. The overall duty cycle required to define engine operating conditions is represented as a nominal shape with a random variation about the mean value. The basic nominal shapes of the duty cycle operational requirements and inlet parameter operation bounds are controlled by the engine contract requirements. These requirements are based on vehicle thrust and operation needs, Figure 6. Environments like vibration have a nominal variation dependent on a components power and/or speed, random variation from hardware geometry and test to test conditions and transient spikes from side loads, pops and chugs. The steady state dynamic loads are represented in the frequency domain for both random and sinusoidal loads, Figure 7.

Since the CLS methodology is to be applied to advanced engines, the loads are being developed from a generic basis. The use of hardware specific random variations like pump efficiency, head rise or flow resistance allow for engine to engine load variations. Accounting for variations in power level, pump speed, and engine inlet operating conditions allow for test to test variation, Figure 8. The use of key variables and appropriate physical and probabilistic models assures the methodology is applicable to variations in the SSME or to new rocket engine designs. The results obtained from the loads spectra models are being compared with available SSME engine measured results and available analytical calculations.

The probabilistic loads model being developed by Battelle is implemented as part of an expert system developed as part of the program. The expert system is a tool to generate and analyze composite loads of a rocket engine design and to supply these loads for use in either deterministic or probabilistic finite element computer codes to perform structural analysis of engine components. The probabilistic models are generic; the statistical information utilized is primarily from the SSME test database. Expert opinion and other engine background data are used where appropriate to complete the loads picture.

The knowledge-based system manages the database, provides expert knowledge relative to the generic probability loadings and generates the individual and composite loads, Figure 9. The Battelle developed ANLOAD module performs the probabilistic modeling and statistical analysis. A database system has been developed to efficiently represent the knowledge. This database system facilitates the communication between the expert system and the knowledge base. The current knowledge base contains information for SSME type engines, system type loads using the influence coefficient method, and local turbine blade load scaling methods.

The expert system is a rule based system. The rules are modularized where each module is designed to solve a particular problem or to perform a task. The load expert system LDEXPT Version 2.0, Figure 10, has rule modules for engine system dependent loads for all four components as well as selected individual local component loads. The rules so far mostly relate to overall process control and information retrieval, Figure 11. The on-going rule development is working on local individual load components and the more complex composite load spectra. Knowledge for the transfer ducts is partially developed and is being added to the system. The other two component loads are being developed.

FIGURE 1

NEED FOR PROBABILISTIC TECHNOLOGY

- INCREASED PERFORMANCE REQUIREMENTS MEAN HIGHER LOADS AND ENVIRONMENTS
- LARGE CHANGES FROM PAST EXPERIENCE BASE
- LIMITED HARDWARE AND TESTING
- DIFFICULTY IN OBTAINING LOCALIZED MEASURED DATA
- DETERMINISTIC METHODS RESULT IN LAYERED CONSERVATISM-JUDGEMENTS, ASSUMPTIONS, MIN/MAX'S
- PROBABILISTIC APPROACH FURNISHES
  - QUANTIFIED LOAD DISTRIBUTIONS
  - SENSITIVITY TO LOAD AND STRUCTURAL VARIATIONS
  - ABILITY TO PROPERLY ASSESS RISK AND FAILURE MODES

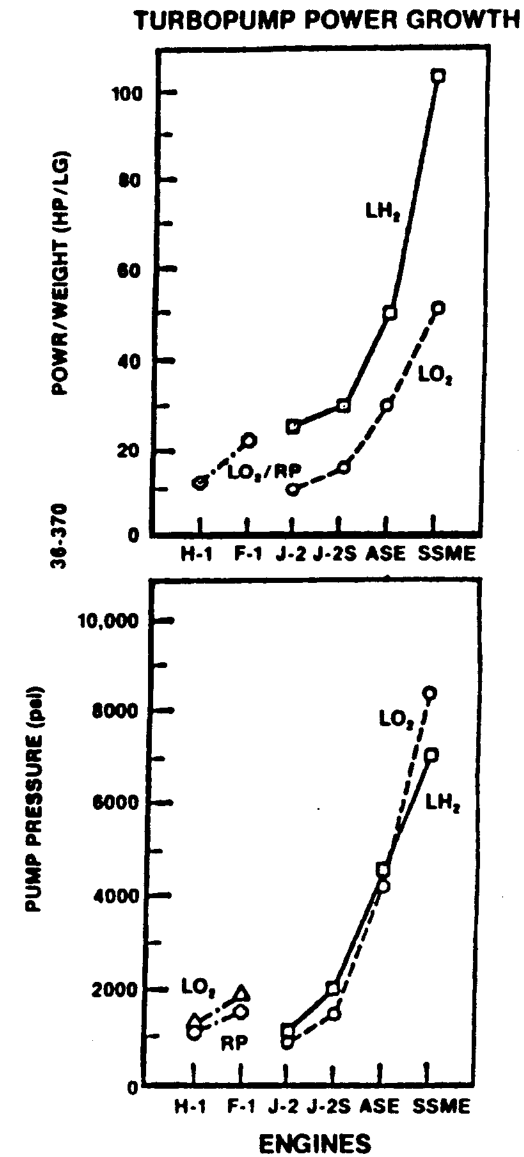
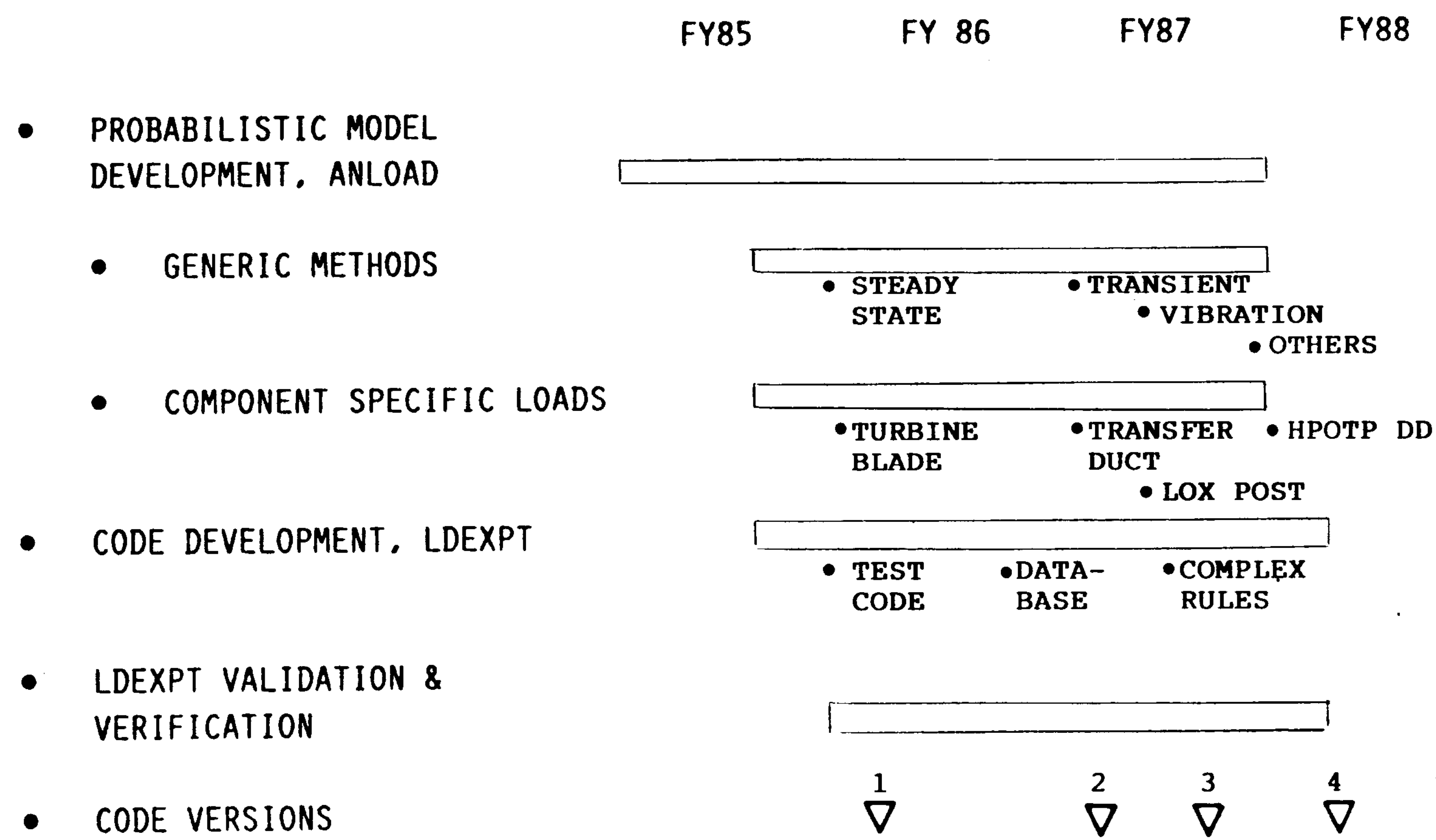


FIGURE 2

COMPOSITE LOADS SPECTRA
BASE PROGRAM



*COMPONENT IMPLEMENTATION AND
LOAD COMPLEXITY IMPROVED IN EACH CODE VERSION

FIGURE 3

CLS ANALYSIS
COMPONENTS AND STANDARD INSTRUMENTATION

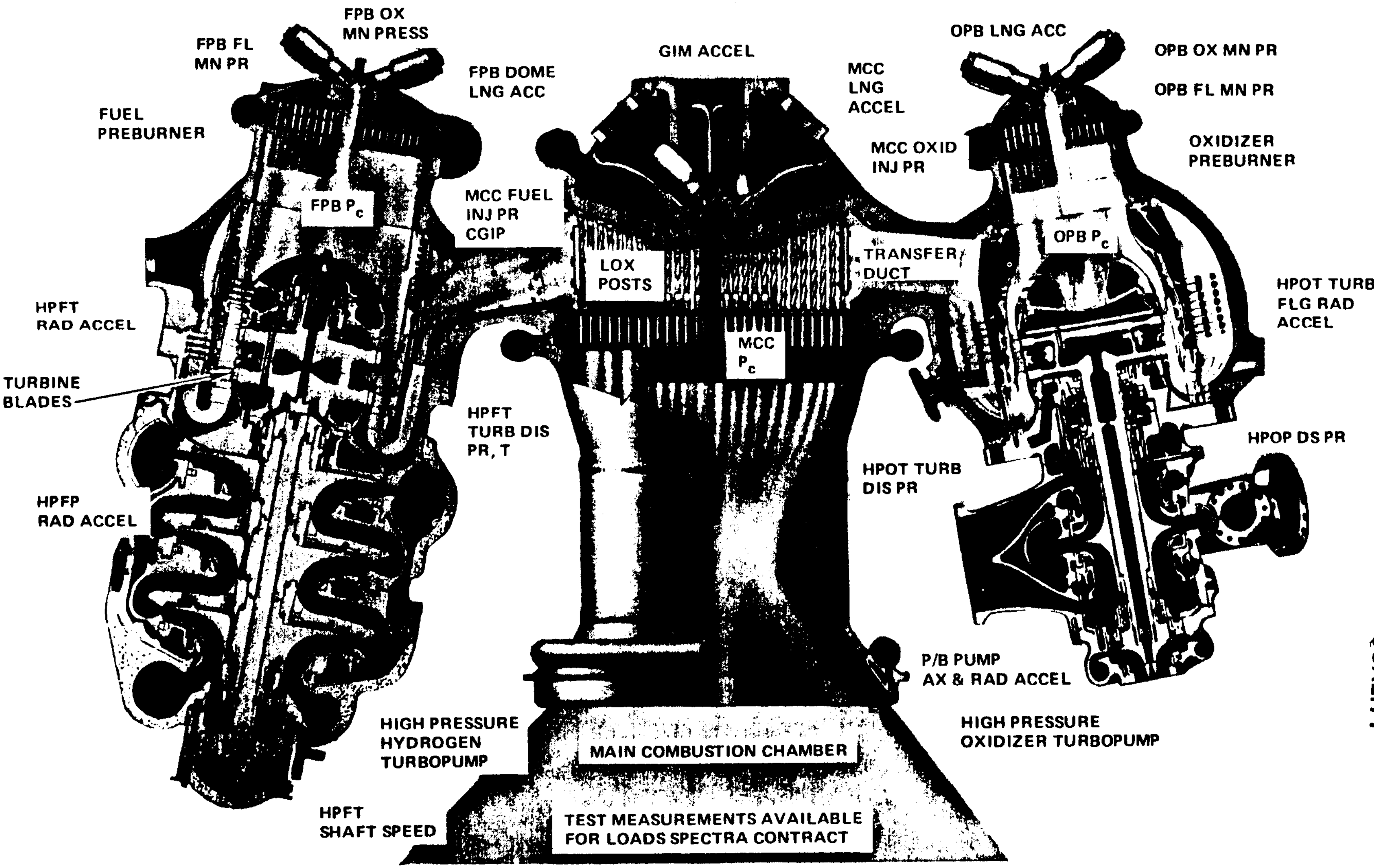


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FIGURE 4
HIGH PRESSURE PUMP DISCHARGE DUCT

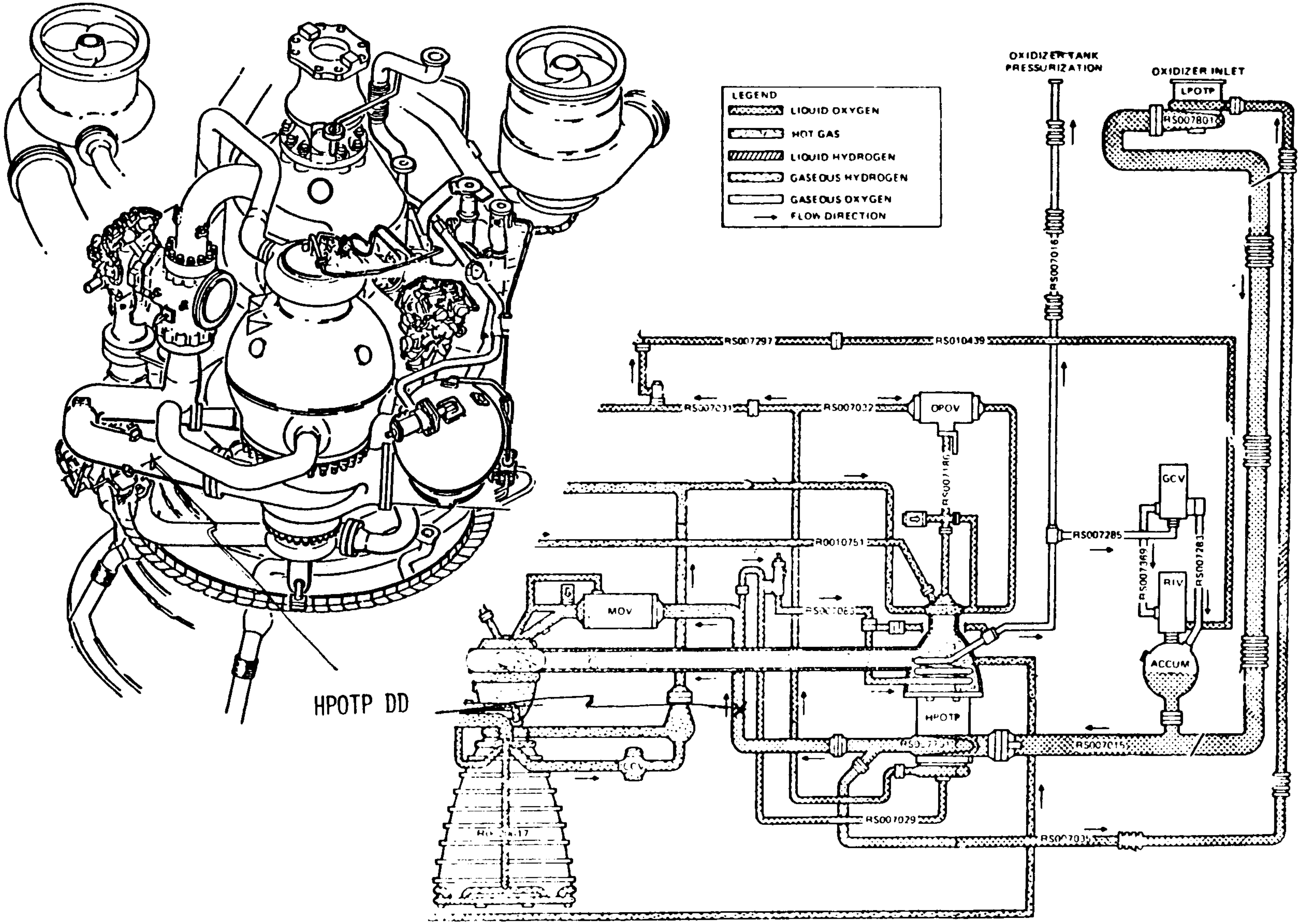

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FIGURE 5

SUMMARY MATRIX OF INDIVIDUAL LOADS VS COMPONENTS

INDIVIDUAL LOAD	TURBINE BLADE	TRANSFER DUCT	LOX POST	HPOTPDD	LOAD FORM
• STATIC PRESSURE	X	X	X	X	DUTY CYCLE*
• DYNAMIC PRESSURE					
• CHUGGING(TRANSIENT)	-	X	-	-	AMS, STATOS
• TURBULENCE					
• SINUSOIDAL (REPEATED PULSE)	X	X			AMS, PSD, STATOS
• RANDOM	-	X	X	X	AMS, PSD
• CENTRIFUGAL	X	-	-	-	DUTY CYCLE*
• TEMPERATURE	X	X	X	X	DUTY CYCLE*
• STRUCTURAL VIBRATION					
• TRANSIENT					
• SIDELOAD	-	X	X	X	AMS, STATOS
• POPS	-	X	X	-	AMS, STATOS
• STEADY STATE					
• SINE	-	X	X	X	AMS, PSD, STATOS
• RANDOM	-	X	X	X	AMS, STATOS
• DEBRIS	X	X	X	-	HISTORY
• RUBBING	X	-	-	-	EXPERT OPINION
• INSTALLATION	-	-	X	X	EXPERT OPINION
• FAB	X	X	X	X	
• FRICTION	X	X	X	-	PSEUDO LOADS
• TOLERANCES	X	X	X	X	

*LOW FREQ. & TRANSIENT

FIGURE 6

CONTRACTURAL REQUIREMENTS

- POWER LEVEL
  - TRANSIENT
  - STEADY STATE
- MIXTURE RATIO - OXIDIZER TO FUEL MASS FLOWRATE REQUIREMENTS AT PUMP INLETS
  - PRESSURES
  - TEMPERATURES

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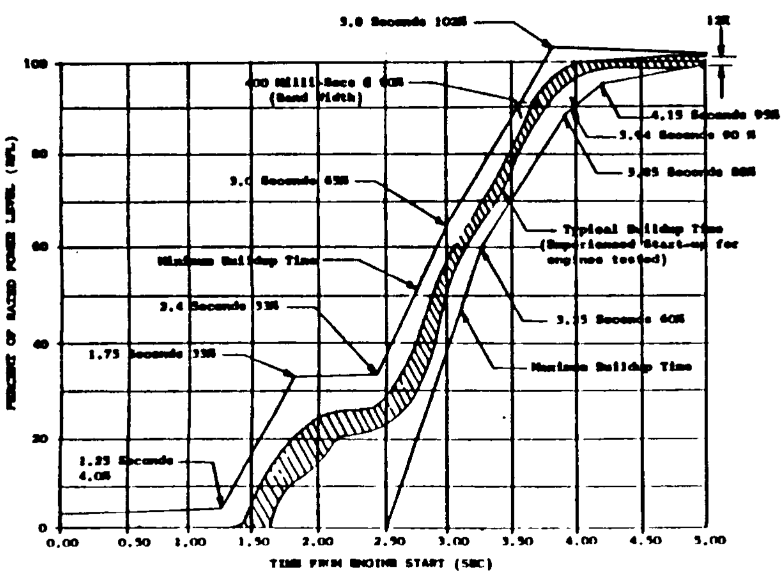
SSME THRUST BUILD-UP LIMITS



SSME FLIGHT DUTY CYCLE

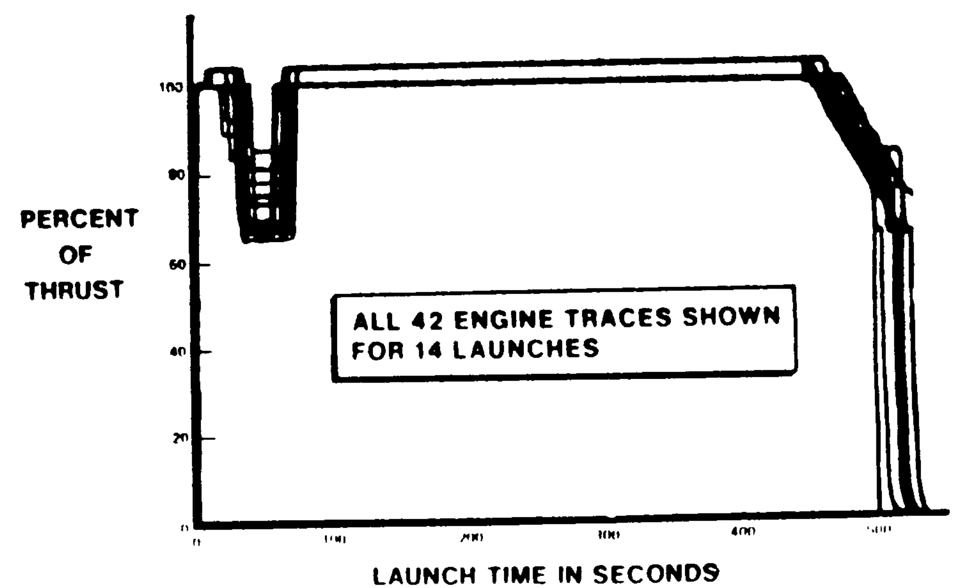


FIGURE 7

MECHANICAL VIBRATION

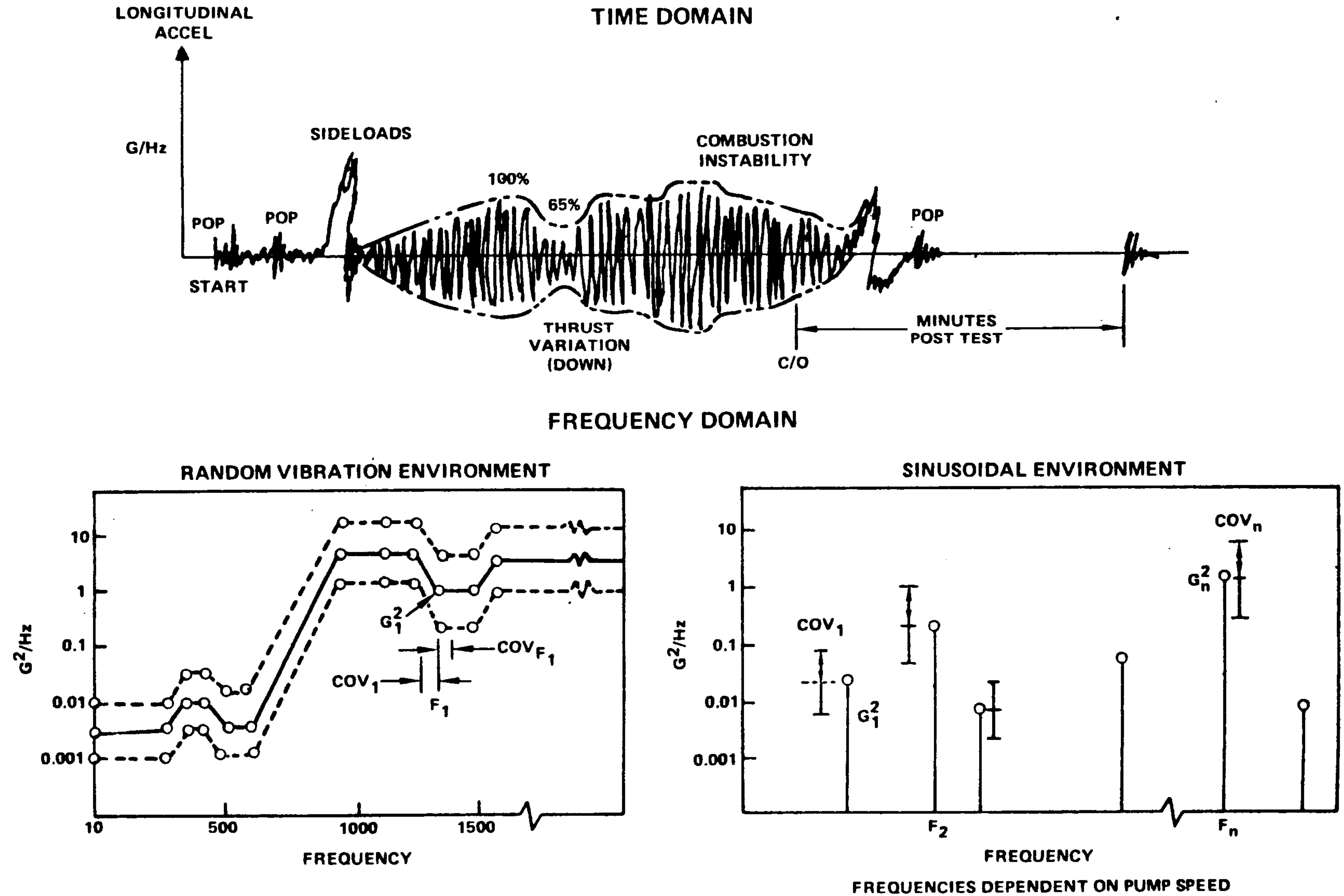


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FIGURE 8

SYSTEM CLASS OF LOADS

- STEADY STATE
  - DIRECT VARIABLES - THRUST, INLET CONDITIONS
  - RANDOM VARIABLES - HARDWARE, TEST VARIATIONS
- TRANSIENTS
  - START AND CUTOFF CONTROLLED
  - LOCAL EFFECTS

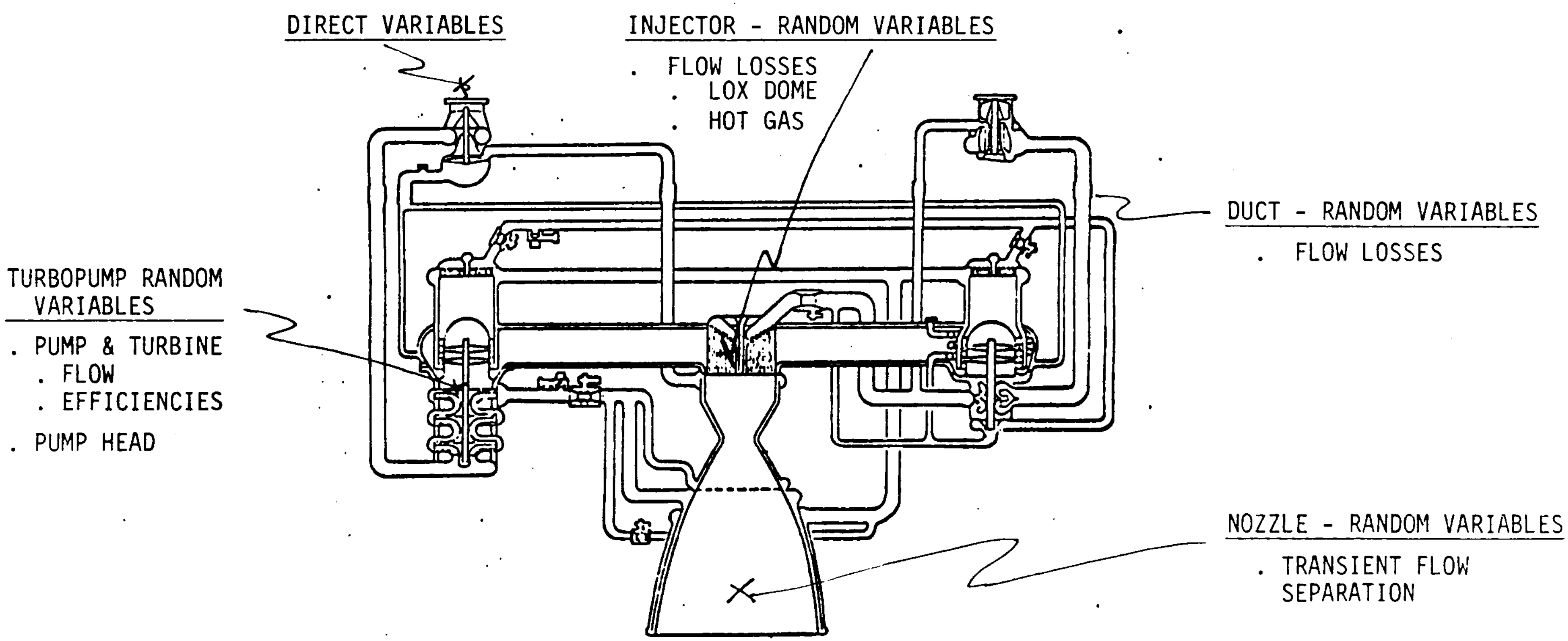

FIGURE 9

LDEXPT LOAD EXPERT SYSTEM

- EXPERT SYSTEM DRIVER
  - DECISION TREE INFERENCE
  - QUERY ON THE DATABASE KEY VARIABLES
- LOAD DATABASE SYSTEM
  - STAND-ALONG DATABASE SYSTEM
  - EXPERT SYSTEM INTERFACE
    - KEY VARIABLES ARE ATTRIBUTES OF THE EXPERT SYSTEM
    - USER/EXPERT SYSTEM SELECT OPTIONS ON KEY VALUES
- SIMPLE WORKING MEMORY MODEL
  - PASSING INFORMATIONS BETWEEN RULE MODULES
- LDEXPT RULE MODULES
  - IMPLEMENTING PROCESS AND CONTROL KNOWLEDGE
    - E.G. RETRIEVING LOAD INFORMATION
  - IMPLEMENTING PROBLEM-SOLVING KNOWLEDGE
    - E.G. SELECTING INDEPENDENT LOADS BASED ON GAINS

FIGURE 10

LDEXPT-LOAD EXPERT SYSTEM

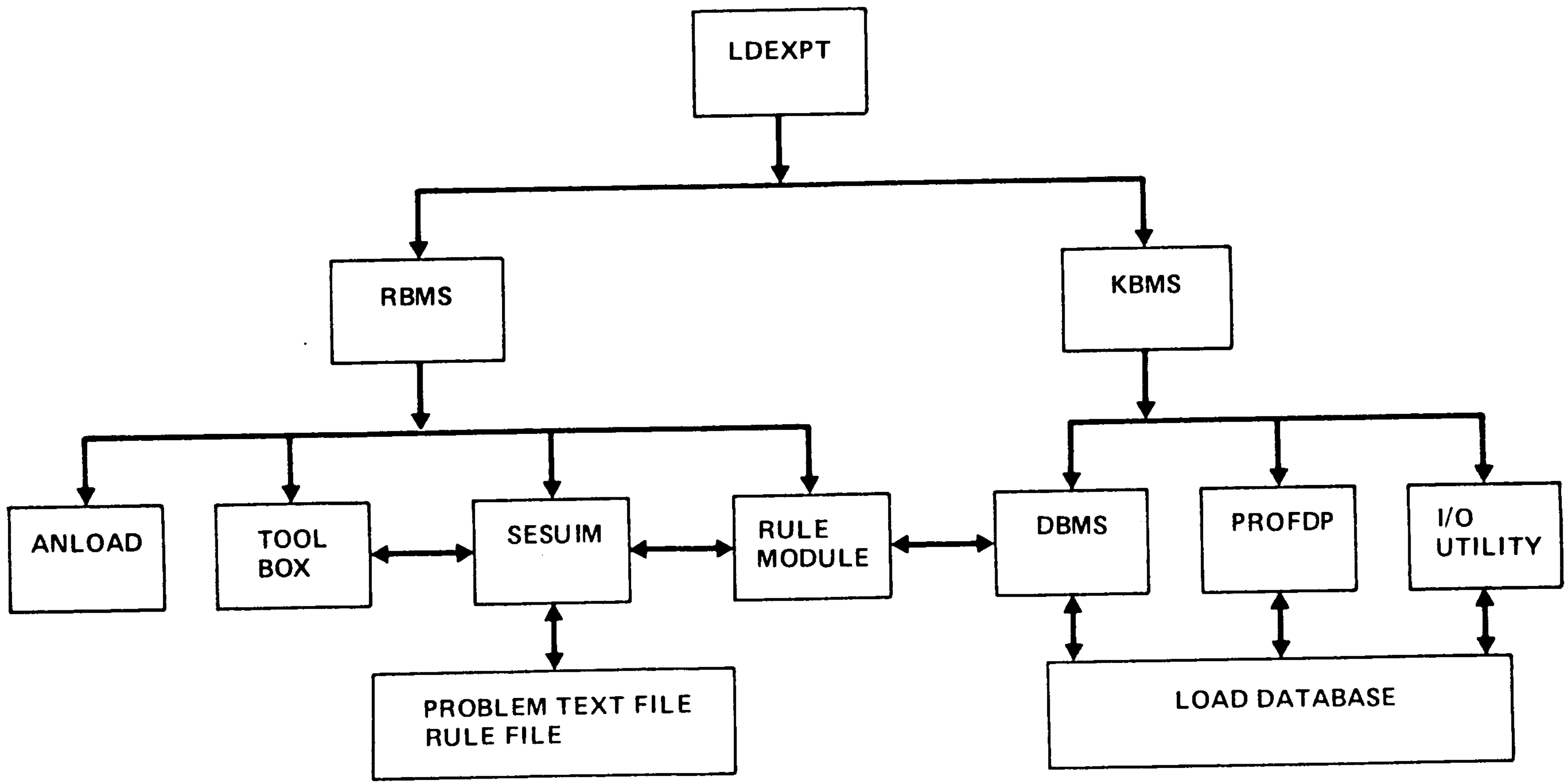

FIGURE 11

LDEXPT LOAD EXPERT SYSTEM

- RULE MODULES
  - MODULAR DESIGN FACILITATES INCREMENTAL DEVELOPMENT
  - COMMUNICATION BETWEEN RULE MODULES IS ACHIEVED WITH THE WORKING MEMORY MODEL
- EXAMPLE: RULE MODEL FOR INFLUENCE COEFFICIENT MODEL

  IF THE DEPENDENT LOAD ID IS N AND THE USER REQUESTS A POINT VALUE OF THE DEPENDENT LOAD CONTRIBUTED FROM THE M MOST INFLUENTIAL INDEPENDENT LOADS

  THEN THE EXPERT SYSTEM WILL SELECT THE M MOST INFLUENTIAL INDEPENDENT LOADS FROM THE LOAD DATABASE, RETRIEVE THE INFLUENCE COEFFICIENT SET AND PERFORM THE DETERMINISTIC INFLUENCE COEFFICIENT MODEL CALCULATION TO OBTAIN THE DEPENDENT LOAD VALUE